AeroSense

Algorithms for Multispectral and Hyperspectral Imagery V 3717-19

Practical Atmospheric Correction Algorithms for a Multi-Spectral Sensor from the Visible through the Thermal Spectral Regions

Thermal Spectral Regions

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Contents

Introduction

Multi-spectral atmospheric correction (AC) methods:

- Dark target (Chavez, 1988, Teillet et al, 1995),

- Spectral channel correlation approach (Liang, 1997),

- Match retrieved ground reflectances to spectral libraries (ATCOR2, Richter , 1996),

- Correct for adjacency effect and terrain effects (Richter, 1998),

- Atmospheric pre-corrected differential absorption to retrieve columnar water vapor over dark targets (APDA, Schlaepfer and Borel, 1998),

- ATmosphere REMoval Program (ATREM, Gao, 1993a),

- Second Simulation of the Satellite Signal in the Solar Spectrum (6S, Vermote, 1996),

- Moderate Resolution Model for LOWTRAN7 (MODTRAN, Kneizys, 1995)

- Multiple temporal looks and fractal dimension analysis (Tornow, 1993), and

- Multiple angular views (Diner et al, 1989).

Land surface temperatures and emissivities retrieval methods:

- Multi-look techniques for water surfaces (Tornow et al, 1994),
- Known emissivity for a channel (Kahle et al, 1980),
- Alpha residuals method (Hook et al, 1992),
- Minimum maximum difference (MMD, Gillespie et al, 1996),
- Spectral smooth emissivity method (SSEM) for hyper-spectral sensors (Borel, 1996),
- Physics-based sea surface temperature (PSST) retrieval (Borel et al, 1999).

Advantages/dis-advantages:

+ Bi-directional reflectance distribution functions and adjacency effects included

− Methods are usually very sensor and scene specific

+ Methods for hyper-spectral sensors work well since atmospheric channels covered ($<5\%$ error)

− Radiative transfer (RT) codes such as ATREM, MODTRAN and 6S require substantial user training

− Methods for multi-spectral sensors difficult to implement if atmospheric channels not available

Pre-processing algorithms for in-scene atmospheric corrections

Pre-processing algorithms:

● Dark target recognition

● Water and dark vegetation masks

● Clouds:

  – Screening for clouds using NDVI

  – Screening for clouds using water vapor slicing

  – Correction of scattering from cirrus clouds

Apparent reflectance:

$$\rho^* = \frac{L_m}{\pi \mu \int_{\lambda_1}^{\lambda_2} R(\lambda) E_0(\lambda) d\lambda}, \qquad (1)$$

where L_m is the measured radiance, μ is the cosine of the angle between the sun and the surface normal, $R(\lambda)$ is the sensors response between wavelengths λ_1 and λ_2 and $E_0(\lambda)$ is the solar irradiance.

Simple algorithms to find dark surfaces and clouds

Dark surface indicator $I_{i;dark}$ **for channel** i **is:**

$$I_{i;dark}(t) = \rho_i^* < t \; min(\rho_i^*),$$

(2)

where $t \approx 1.1$

Multiple channel indicator:

$$I_{1,3,5;dark} = I_{1;dark}(t_1) \cap I_{3;dark}(t_3) \cap I_{5;dark}(t_5).$$

(3)

Water mask:

$$I_{red,nir;water}(t_{ndvi}, t_{red}) = \left[\frac{\rho_{nir}^* - \rho_{red}^*}{\rho_{nir}^* + \rho_{red}^*} < t_{ndvi} \right] \cap \left[\rho_{red} < t_{red} \right],$$
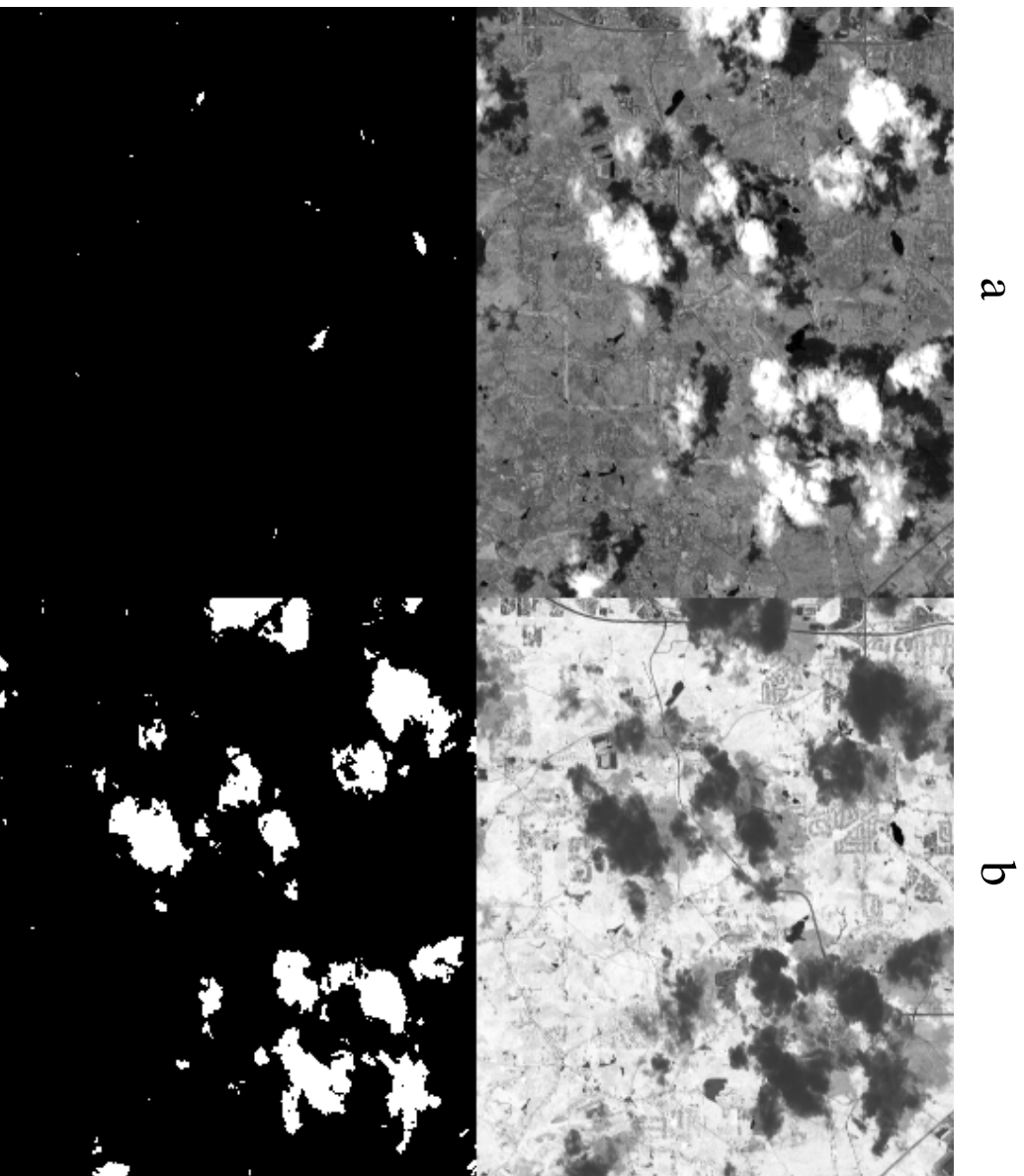
(4)

where $t_{ndvi} \approx 0.$ and $t_{red} \approx 0.3$

Cloud mask:

$$I_{red,nir;cloud}(t_{ndvi}, t_{nir}) = \left[\frac{\rho_{nir}^* - \rho_{red}^*}{\rho_{nir}^* + \rho_{red}^*} < t_{ndvi} \right] \cap \left[\rho_{nir} > t_{nir} \right],$$

(5)

where $t_{ndvi} \approx 0.1$ and $t_{nir} \approx 0.3$.

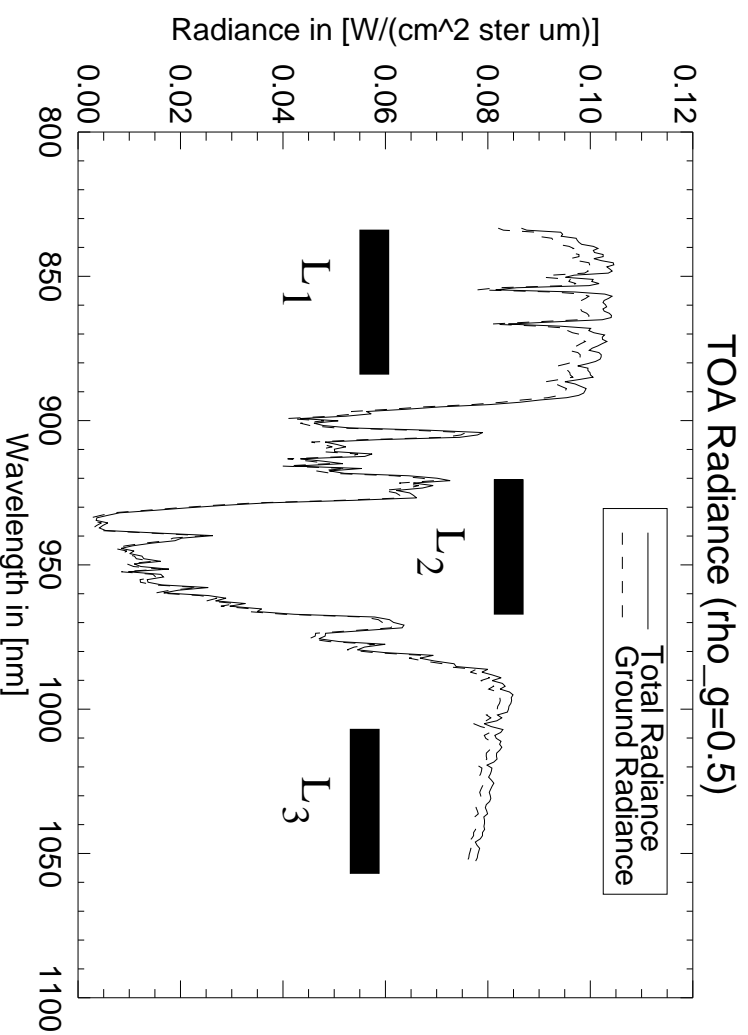**Example of cloud and water mask**

a

b

c

d

(a) AVIRIS derived reflectance image in NIR channel, (b) NDVI, (c) water mask (t_{ndvi}=0.041 and $t_{red} = 0.3$) and (d) cloud mask ($t_{ndvi} = 0.131$ and $t_{nir} = 0.3$).

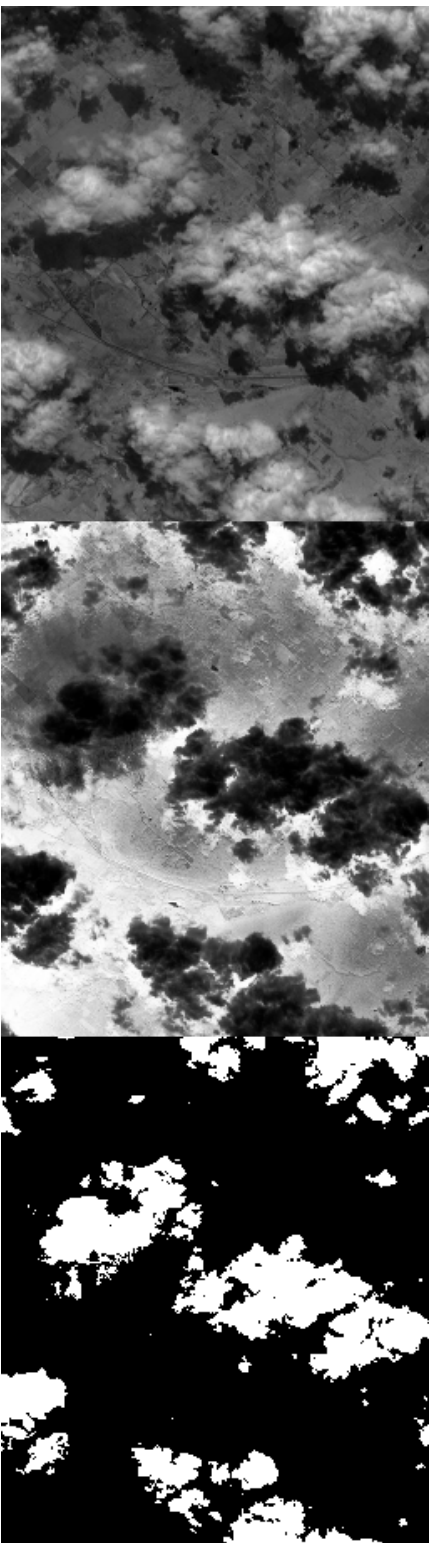*Water vapor slicing method (Gao and Goetz, 1991)*

$$CIBR(L_1, L_2, L_3) = \frac{L_1 + L_3}{2\,L_2}.$$

(6)

Computed radiances near 940 nm water vapor absorption feature for a ground reflectance of $\rho_g = 0.5$.

TOA Radiance (rho_g=0.5)

Radiance in [W/(cm^2 ster um)]

Wavelength in [nm]

——— Total Radiance
– – – Ground Radiance

L_1
L_2
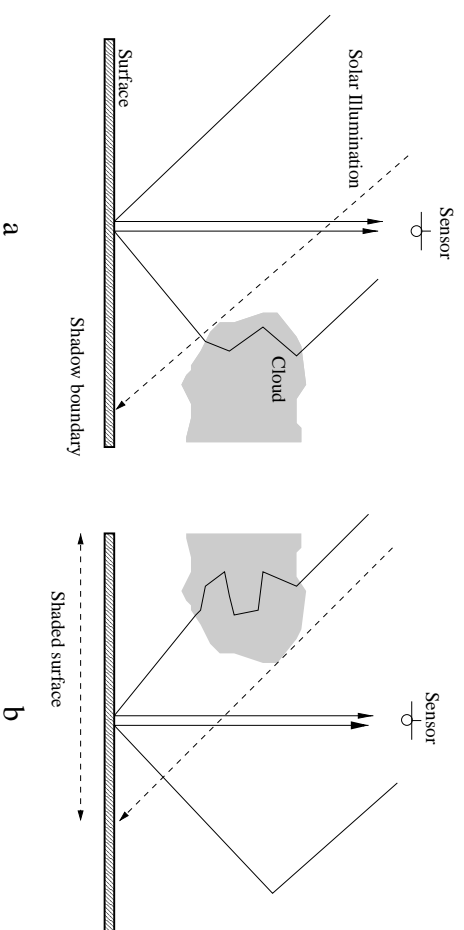L_3

Water vapor derived cloud mask:

a   b   c

(a) NIR channel and (b) histogram equalized CIBR which if thresholded yields (c) the cloud mask.

Hypothesis to explain larger water vapor amounts: photon paths for a) above surface surrounding a cloud and b) in the cloud shadow.

Simple visual correction algorithm for cirrus clouds

Linear regression based:

$$DN_{17;corrected}(x,y) = DN_{17}(x,y) - \{600. + 6.2\ smooth(DN_{111}(x,y),21)\},$$

where $smooth()$ is a 21 x 21 rectangular smoothing filter which smoothes the inherently noisy 1.38 μm data.

a

b

c

Histogram equalized images of (a) 1.38 μm channel with a visible cirrus cloud, (b) channel 17 (0.547 μm) visible channel with cirrus cloud contamination and (c) cirrus corrected channel 17.

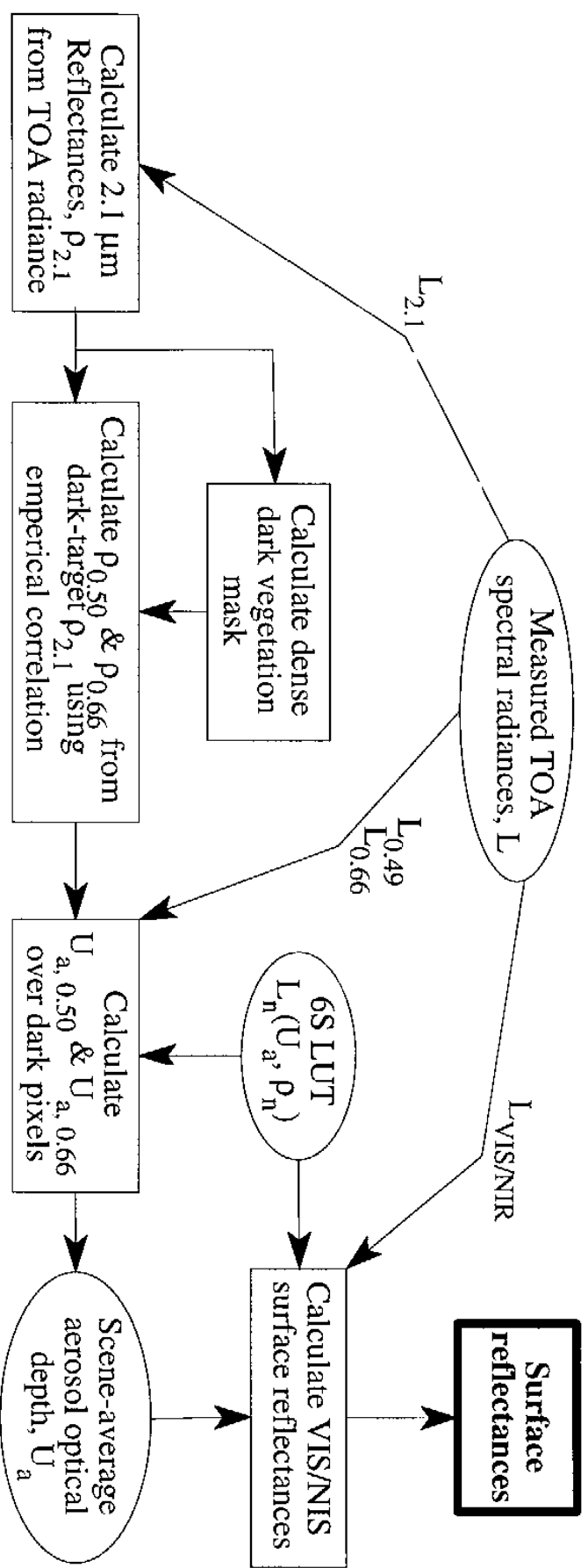**Requirements for algorithms:**

- Retrieve atmospheric parameters from data
- Estimate aerosol optical depth from data over dense dark vegetation
- Estimate path radiance from data over dark water
- Computationally simple
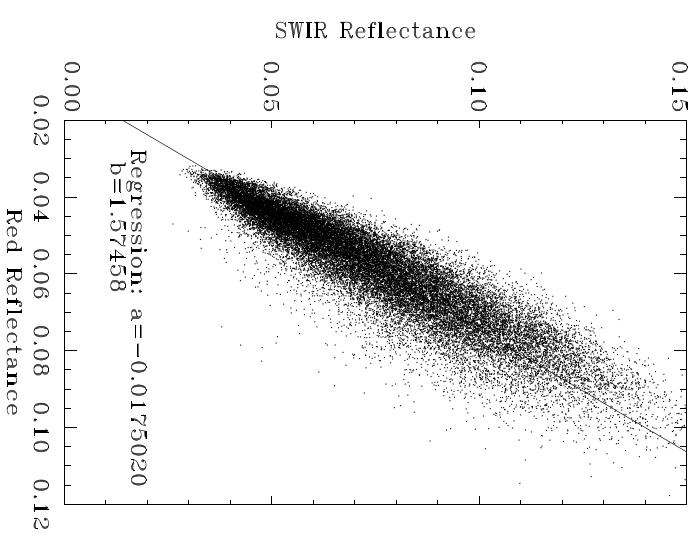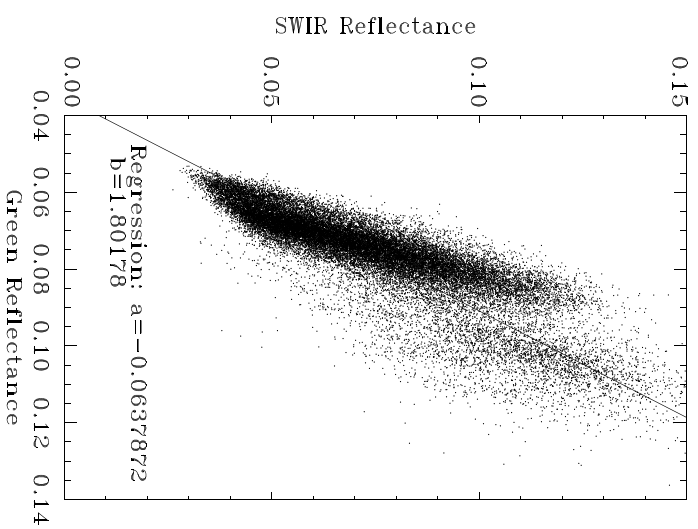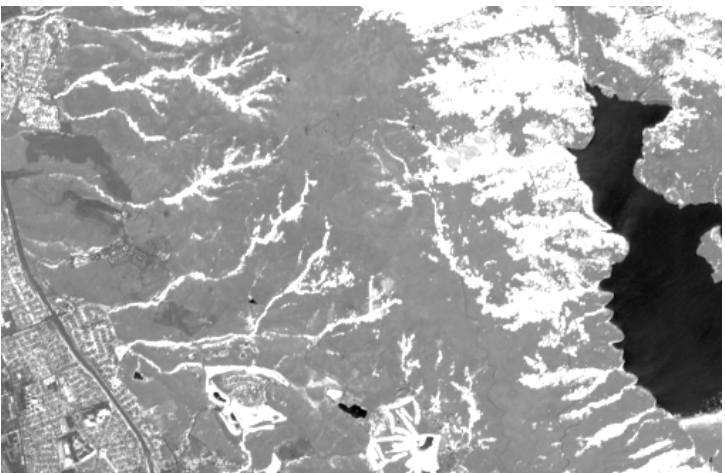- Use a readily available atmospheric radiative transfer code

Channel A-blue

TOA Radiance [w/m2/sr/mic]

Visibility in [km]

Channel A-blue

TOA Radiance [w/m2/sr/mic]
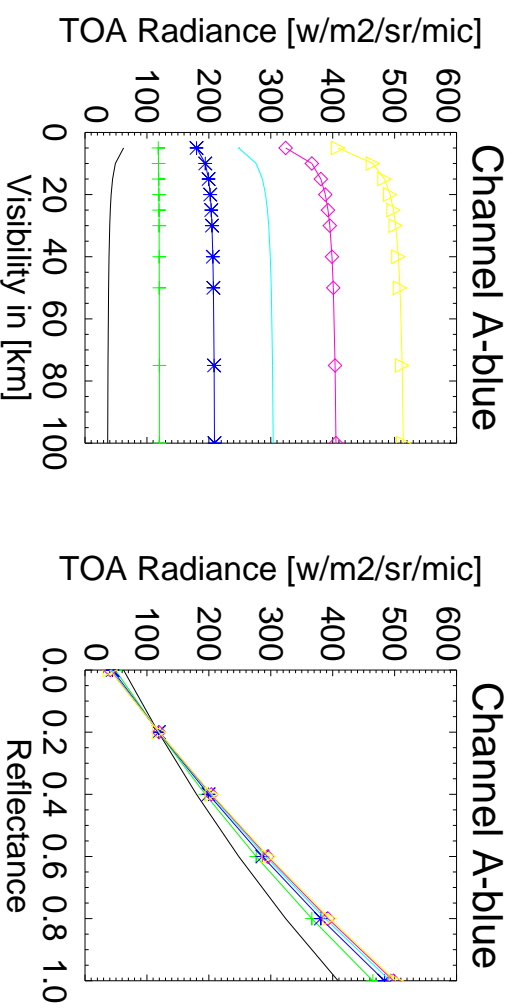
Reflectance

Example of an AC for MTI's channel A (blue).

Atmospheric correction over dark vegetation

TOA reflectance correlations over dense dark vegetation

a

b

c

(a) NDVI image (white is where NDVI > 0.5) TOA reflectances in (b) green and (c) red channels correlated to the 2.1 μm SWIR channel for: $(NDVI > 0.5) \cap (\rho_{2.1\ \mu m} < 0.15$

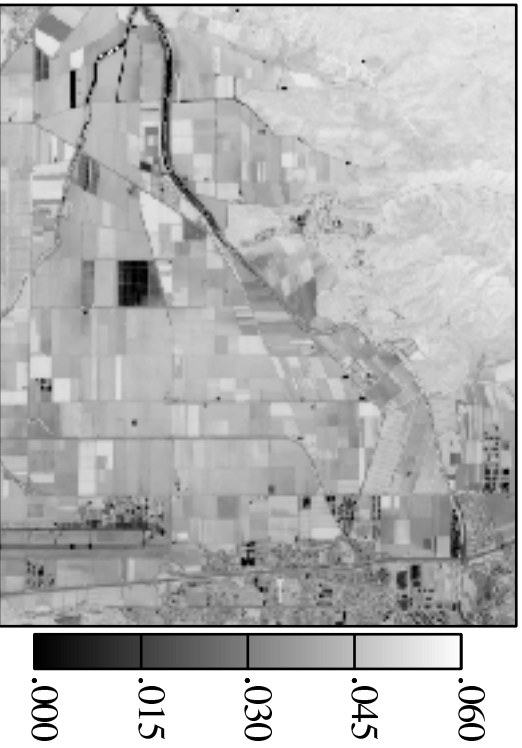Example of an atmospheric correction over Camarillo, CA

(a) Band A TOA Reflectance

(b) Dense Dark Vegetation Map

(c) Band A Surface Reflectance

(d) Band A TOA Refl.– Surface Refl.

(a) TOA, (b) dense dark vegetation, (c) ground reflectance and (d) reflectance error images for blue channel over Camarillo, CA.
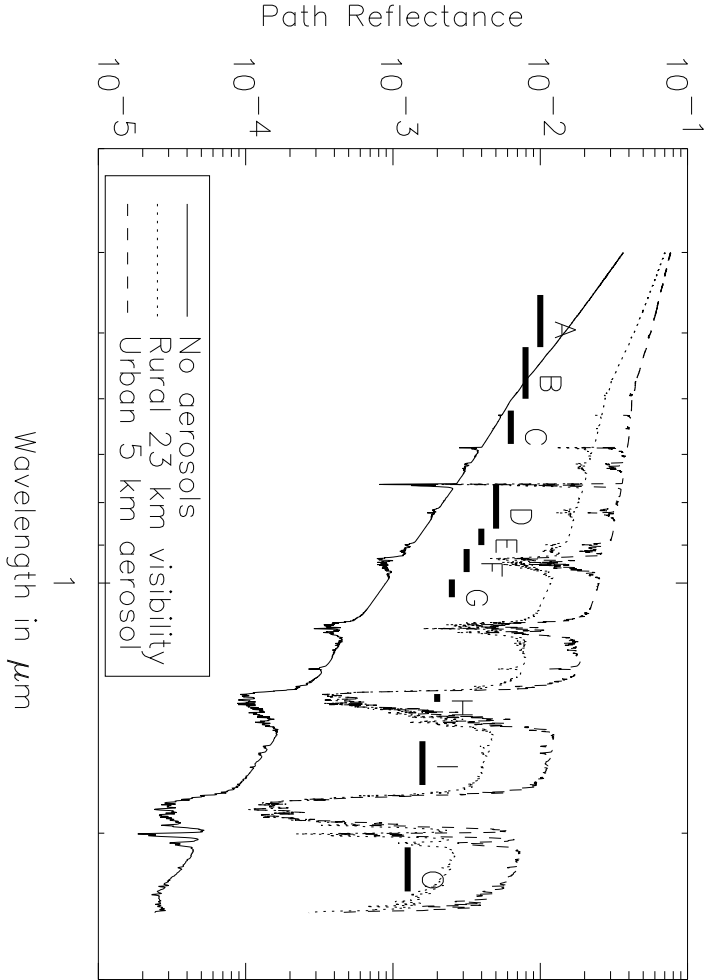
Atmospheric correction over water

Steps:

1. Select dark water pixels.

2. Perform a linear fit to the minimum apparent reflectances $\rho^*_{i;min}$, $i = 1, 2, 3$ (Landsat band numbers) with $y = a_{vis} + b_{vis}x$ for $x_i = \log_{10}(\lambda)$ and $y_i = \log_{10} \rho^*_i$, where $i = 1, 2, 3$ are the visible blue, green and red channels.

3. Perform a linear fit to the minimum apparent reflectances $\rho^*_{i;min}$, $i = 4, 5, 7$ with $y = a_{swir} + b_{swir}x$ for $x_i = \log_{10}(\lambda)$ and $y_i = \log_{10} \rho^*_i$, where $i = 4, 5, 7$ are the short-wave infrared .8, 1.65 and 2.2 μm channels.

4. Compute the atmospheric path reflectance corrected ground reflectance using the fitting coefficients from steps 2 and 3: $\rho^*_{i;corrected} = \rho^*_i - \rho_{i;path}$, where $\rho_{i;path} = 10.^{a_m + b_m \log_{10}(\lambda_i)}$, where $m = \{vis, swir\}$.

5. Check for negative apparent corrected reflectances $\rho^*_{i;corrected}$ and repeat steps 2 and 3 if necessary choosing a different set of pixels by varying the threshold t_{ndvi} to determine the water surfaces.

Atmospheric correction:

$$\rho_{i;corrected}^* = \rho_i^* - \rho_{i;path}, \text{ where } \rho_{i;path} = 10.^{a_m + b_m \log_{10}(\lambda_i)}.$$

Aerosol Type	a_{vis}	b_{vis}	a_{swir}	b_{swir}
No Aerosol	-3.09	-4.15	-3.07	-4.05
23 km Rural	-1.99	-2.1	-1.96	-2.15
5 km Urban	-1.63	-1.22	-1.66	-1.74

Fitting coefficients to the path reflectance in a mid-latitude summer atmosphere using MOD-TRAN 3.5 results for 4-stream DISORT RT calculation.

MTI Band	Wavelength Range in μm	Landsat Band
A	0.45–0.52	1
B	0.52–0.60	2
C	0.62–0.68	3
D	0.76–0.86	4
E	0.86–0.90	
F	0.91–0.97	
G	0.99–1.04	
H	1.36–1.39	
I	1.55–1.75	5
O	2.08–2.35	7

TOA path reflectances for 10 MTI channels as a function of aerosol conditions.

Uncorrected true color image

Atmospherically corrected image

Use NDVI and NIR reflectance to determine the water mask

Correlate dark water pixels in visible channels and correct for path reflectance

Conclusions

- Dark target and cloud screening are important.

- Results from many runs of RT codes need to be converted to LUT schemes.

- If available atmospheric bands are useful, e.g. 0.94 μm and 1.38 μm, to retrieve clouds and correct for scattering.

- Elevated levels of water vapor were found near clouds and in cloud shadows.